Friday, July 31, 1998
COSMIC-RAY EFFECTS
8:30 a.m.   Ussher Theatre

Chairs: K. C. Welten
**   R. Michel**

Jull A. J. T.*   Bland P. A.   Klandrud S.   McHargue L. R.   Nishiizumi K.   Caffee M. W.
Cosmogenic Radionuclide Studies of Desert Meteorites, Including a New Lunar Meteorite

Welten K. C.*   Nishiizumi K.   Caffee M. W.   Wieler R.
Terrestrial Ages of H Chondrites from Frontier Mountain, Antarctica

Nishiizumi K.*   Caffee M. W.
Measurements of Cosmogenic Calcium-41 and Calcium-41/Chlorine-36 Terrestrial Ages

Michel R.*   Gloris M.   Neumann S.   Leya I.
Neutron Cross Sections for Physical Model Calculations of Cosmogenic Nuclide Production Rates

Patzer A.*   Schultz L.
The Exposure Age Distribution of Enstatite Chondrites

Terribilini D.*   Eugster O.   Vogt S.   Wang D.
Cosmic-Ray Exposure Ages of the Two Iron Meteorites, Rafrüti and Ningbo, and the Two Mesosiderites, Weiyuan and Don Ujimqin

Merchel S.*   Herpers U.   Knie K.   Faestermann T.   Korschinek G.   Gloris M.   Michel R.
Iron-60 in Meteorites

COSMOGENIC RADIONUCLIDE STUDIES OF DESERT METEORITES, INCLUDING A NEW LUNAR METEORITE.

A. J. T. Jull[1], P. A. Bland[2], S. Klandrud[1], L. R. McHargue[1], K. Nishiizumi[3], and M. W. Caffee[4], [1]National Science Foundation Arizona, AMS Facility, University of Arizona, Tucson AZ 85721, USA, (jull@u.arizona.edu), [2]Open University, Milton Keynes, MK7 6AA, UK, [3]Space Sciences Laboratory, University of California, Berkeley CA 94720-7450, USA, [4]Lawrence Livermore National Laboratory, Livermore CA 94550, USA.

A number of the world's and semi-arid regions have proved to be great stores of meteorites. There is now much evidence that meteorites can survive for long periods of time in such environments. Large numbers of meteorites were recovered from wind deflation zones in Roosevelt County, New Mexico. Many more meteorites have been recovered from such diverse areas as the deserts of North Africa, Arabia, North and South America and Western Australia.

More than 3.8 million km^2 of Australia is arid or semi-arid land, and provides suitable conditions for the long-term storage of meteorites. In the Nullarbor region, there is good evidence that meteorites are lying near where they fell. The northern Sahara Desert in Africa has also become a prolific source of meteorites. The study of the terrestrial ages of these meteorites gives us useful information concerning the storage and weathering of meteorites and the study of fall times and terrestrial age. The most useful cosmogenic radionuclide for determination of terrestrial ages of many meteorite collection areas is ^{14}C ($t_{1/2}$=5730 y). For the Nullarbor and for some other locations, we can show an approximately exponential drop-off of number of meteorites with age. Jull et al. [1,2] and Wlotzka et al [3] have reported on terrestrial ages of meteorites from these regions. By comparison with the Nullarbor, other arid and semi-arid sites such as the Sahara desert and Roosevelt County show evidence for climatic effects (for the Sahara) or burial of the meteorites in cover soils (as in Roosevelt County), and subsequent re-exposure to the elements at a later time. Within the limits of this data-set, we can state that the Nullarbor and Sahara meteorites show an exponential decrease of number of finds with terrestrial age to at least 30 ky. We are currently evaluating some terrestrial ages in meteorites where all the ^{14}C has decayed, using other cosmogenic radionuclides such as ^{41}Ca (1.0×10^5 y) and ^{36}Cl (3.0×10^5 y).

Since weathering gradually destroys meteorites, in a given population of finds the resulting distribution should show some kind of exponential dependence on age. The distribution of meteorite terrestrial ages is easily understood in the case of a collection where all meteorites fell directly on the collection area. The meteorites then should eventually disintegrate and therefore, the number will decrease with increasing age, and so there should be more young meteorites than older ones. This is the expected distribution based on the model of meteorite accumulation discussed by Jull et al.. [4]. However, we know that sites such as Roosevelt County, New Mexico that do not follow this relationship.

Many stony meteorites survive in desert environments for long periods of time. Some interesting achondrites have also been recovered from these desert regions, although the vast majority are ordinary chondrites. Two lunar meteorites, Calcalong Creek and Dar al Gani 262 have been recovered from these "hot" deserts. We will report on radionuclide concentrations and estimated terrestrial and exposure ages in a second lunar meteorite recovered from the Dar al Gani region [5]. We thank the Max-Planck-Institut für Chemie, Mainz and Western Australian Museum for provision of samples.

Distribution of Terrestrial Ages from desert environments
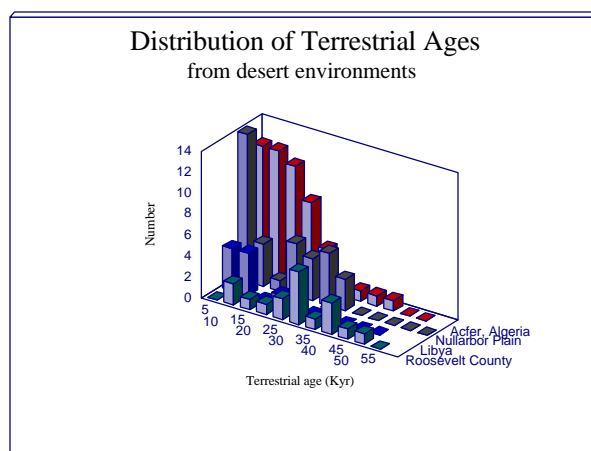
References: [1] Jull A. J. T. et al. (1990) *GCA, 54,* 2895–2899. [2] Jull A. J. T. et al. (1995) *LPI Tech. Rep., 95-02,* 37–38. [3] Wlotzka F., Jull A. J. T., and Donahue D. J. (1995) *LPI Tech. Rep., 95-02,* 72. [4] Jull A. J. T. et al. (1993) *Meteoritics, 28,* 188–195. [5] Zipfel J. et al. (1998) this volume.

TERRESTRIAL AGES OF H-CHONDRITES FROM FRONTIER MOUNTAIN, ANTARCTICA.

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Introduction: Terrestrial ages of Antarctic meteorites provide information on meteorite accumulation mechanisms, transport times and mean weathering lifetimes. In the past two decades more than 4000 meteorites have been found near Frontier Mountain, North Victoria Land [1-2], but so far terrestrial age data have been reported for only a few of these meteorites [1,3]. The radionuclide most used for Antarctic meteorites is ^{36}Cl, because its half-life of 301,000 years is well-suited to determine ages between 10^5–10^6 years and its production rate in the metal phase is well-known and relatively insensitive to shielding [4]. The use of an average saturation value of 22.1 ± 2.8 dpm/kg (2) introduces an error of 55,000 years in the terrestrial age. In an effort to reduce this error, we determined shielding-corrected terrestrial ages based on the relation between the $^{36}Cl/^{10}Be$ ratio and the ^{10}Be concentration in the metal phase [5]. Exposure age data are required in order to correct for undersaturation of radionuclides at the time of fall. We therefore measured ^{10}Be, ^{26}Al and ^{36}Cl in the metal phase as well as He, Ne and Ar in bulk samples of 25 H-chondrites and 1 L-chondrite from Frontier Mountain.

Results:. The noble gas and radionuclide data of most samples have been reported previously [6]. The majority of the exposure ages cluster around the major H-chondrite peak between 4–10 million years, whereas two meteorites have ages >20 million years.

Terrestrial ages: The measured ^{36}Cl concentrations range from 12.2 to 23.7 dpm/kg, which implies that none of the meteorites is older than 300,000 years. By combining the ^{10}Be and ^{36}Cl concentrations with the ^{21}Ne-exposure ages, we calculated the $^{36}Cl/^{10}Be$ terrestrial age of each meteorite. For meteorites with $^{22}Ne/^{21}Ne$ ratios >1.15, the $^{36}Cl/^{10}Be$ age is 30,000 to 50,000 years higher than the simple ^{36}Cl age, because the ^{36}Cl production rate in the metal phase increases from 22.1 atom/min/kg to about 24.5 atom/min/kg with increasing $^{22}Ne/^{21}Ne$ ratio. For heavily shielded meteorites with $^{22}Ne/^{21}Ne$ ratios <1.08, the $^{36}Cl/^{10}Be$ ages are up to 180,000 years lower than the simple ^{36}Cl ages. Since most of the exposure ages are >4 million years, the uncertainty in the exposure age has only a minor effect on the $^{36}Cl/^{10}Be$ ages. In general the 2 -uncertainties in the shielding-corrected $^{36}Cl/^{10}Be$ ages are about 40,000 years, about 30% lower than for the simple ^{36}Cl ages. For five meteorites of two distinct falls, the $^{36}Cl/^{10}Be$ ratios plot significantly above the relation given by [5], which indicates they were irradiated for a shorter time than their ^{21}Ne exposure ages suggest. While a possible complex exposure history is being investigated, we adopted the ^{36}Cl ages for these meteorites.

The obtained terrestrial ages for all 26 meteorites analyzed are less than 200,000 years (Fig. 1). The terrestrial age distribution, corrected for pairing [6], suggests that meteorites found in the Moraine are older than those found on the blue ice, although statistics are still poor. In comparison with other stranding areas, Frontier Mountain is much younger than Allan Hills and Lewis Cliff, but similar in age to the Yamato Ice-fields [4]. The maximum terrestrial age of ~200,000 years might well be explained by the minimum surface exposure age of ~170,000 years for Frontier Mountain bedrock, based on our unpublished ^{10}Be and ^{26}Al data in quartz.
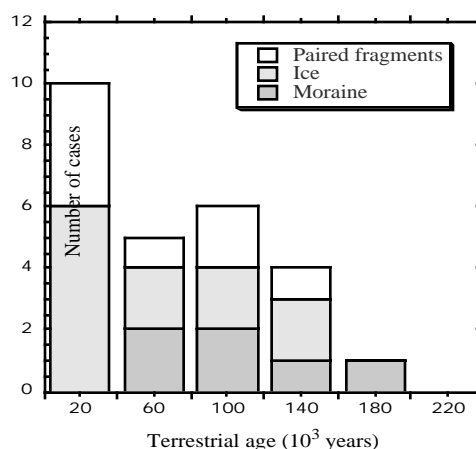
Fig. 1. Terrestrial ages of 26 ordinary chondrites from the Frontier Mountain stranding area.

References: [1] Delisle G. et al. (1989) *Geol Jb.* E38, 483–513. [2] Delisle G. et al. (1993) *Meteoritics, 28,* 126–129. [3] Nishiizumi K. et al. (1989) *EPSL, 93,* 299–313. [4] Nishiizumi K. (1995) *LPI Tech. Rpt.* 95-02, 53–55. [5] Nishiizumi K. et al. (1997) *Meteoritics, 32,* A100. [6] Wieler R. et al. (1998) *23rd NIPR Symp. Ant. Met.,* Tokyo, Japan.

MEASUREMENTS OF COSMOGENIC ^{41}CALCIUM AND ^{41}CALCIUM-^{36}CHLORINE TERRESTRIAL AGES.

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The half-life of ^{41}Ca (1.04x10^5 years) fills a gap between the half-lives of ^{14}C (5730 years) and ^{36}Cl (3.01x10^5 years) and is therefore one of the only radionuclides that can be utilized in understanding processes that occur in nature on a time-scale of tens of thousand years to several hundred thousand years.

Antarctic meteorites possess long terrestrial ages, falling within this age span. Three cosmogenic nuclides, ^{14}C, ^{81}Kr (2.1x10^5 years), and ^{36}Cl, are used for terrestrial age determinations. Although the ^{36}Cl terrestrial age method is well established and robust, the ^{36}Cl half-life is nevertheless longer than the terrestrial ages of many Antarctic meteorites. Since most of terrestrial ages are between a few tens of thousands years and a few hundred thousand years, ^{41}Ca is potentially the most sensitive chronometer for terrestrial age determinations [1]. The accuracy of ^{41}Ca-based terrestrial ages will be 30–50% improved relative to ages determined by the ^{36}Cl method for those meteorites with less than a few hundred thousand years terrestrial age. Accordingly, the improved accuracy of this radionuclide will give us substantially better age resolution.

The terrestrial age of the meteorite, T, can be calculated by a simple formula:

$$T = \frac{1}{\lambda} \ln\left(\frac{A_s}{A_m}\right) \qquad (1)$$

where λ is the decay constant, A_s is the activity at fall (saturation activity in most cases), and A_m is the observed activity. The difference between these two is proportional to the terrestrial age.

Although independent ^{36}Cl and ^{41}Ca terrestrial ages can be determined using equation (1) the variation in saturation activities, due to shielding effects, of ^{36}Cl and ^{41}Ca in the metallic phase varies by 10–20 % inside meteorites of average size, which in turn yields an uncertainty in the terrestrial age determination. Since the nuclear production systematics of ^{36}Cl and ^{41}Ca are similar, measurements of both ^{36}Cl and ^{41}Ca from an aliquot from the metallic phase effectively eliminates shielding as a consideration. The terrestrial age, T, is thus given by:

$$T = \frac{1}{\lambda_{Ca} - \lambda_{Cl}} \ln\left(\frac{Cl_m}{Ca_m} \cdot \frac{P_{Ca}}{P_{Cl}}\right) \qquad (2)$$

where λ_{Ca} and λ_{Cl} are the decay constants of ^{41}Ca and ^{36}Cl, Ca_m and Cl_m are the measured activities of ^{41}Ca and ^{36}Cl, and P_{Ca}/P_{Cl} is the production rate ratio of ^{41}Ca to that of ^{36}Cl in the metallic phase. P_{Ca}/P_{Cl} will be obtained by measuring ^{41}Ca and ^{36}Cl in a meteorite fall. The ratio P_{Ca}/P_{Cl} was expected to be approximately constant.

To determine absolute ^{41}Ca concentrations a reliable ^{41}Ca standard is essential so we prepared new ^{41}Ca AMS standards. A highly enriched Ca sample (^{41}Ca/Ca = 0.01232) was chemically purified and sequentially diluted with natural Ca. A series of AMS standards having ^{41}Ca/Ca ratios of 9.3x10^{-9} to 5.9x10^{-13} were prepared. Excellent linearity was obtained from 5.9x10^{-13} to 1.2x10^{-10} ^{41}Ca/Ca. The present background level for the processed sample is ~7x10^{-14}.

We selected Fe and stony meteorites representing a wide range of shielding condition to observe any depth dependence of the production rate of ^{41}Ca and ^{36}Cl in the metal. In falls, ^{36}Cl is an indicator of shielding depth. The relationship between the production ratio and shielding can be seen in the graph. The falls are represented by filled circles in the figure. Although the ^{41}Ca measurements contain larger errors, the ratio seems to increase as a function of shielding. This observed variation in production rate ratio indicates that eq. (2) is not valid for the calculation of terrestrial ages over a wide range of shielding conditions. However, at lower shielding conditions the ratio is almost constant, 1.01±0.08, and agrees with previous work [2]. The ^{41}Ca and ^{36}Cl concentrations from finds were also measured and are shown in the figure. Meteorites having discernible terrestrial ages will plot below the production line. The trajectory off this line is a function of the half-lives and the terrestrial age. Displacements from the solid line toward lower left indicate increasing terrestrial age. The terrestrial ages calculated by this method are in good agreement with those by ^{10}Be-^{36}Cl/^{10}Be method [3]. We anticipate the application of the technique to samples for which other techniques are inadequate in the near future.

References: [1] Nishiizumi K. (1986) *LPI Tech. Rpt. 86-01,* 71–73. [2] Fink D. *et al.* (1991) *EPSL. 107,* 115–128. [3] Nishiizumi K. *et al.* (1997) *Meteorit. Planet. Sci. 32,* A100.
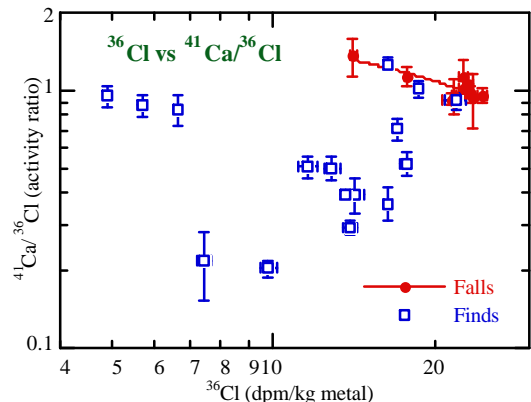
NEUTRON CROSS SECTIONS FOR PHYSICAL MODEL CALCULATIONS OF COSMOGENIC NUCLIDE PRODUCTION RATES.

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Production by GCR particles of cosmogenic nuclides in meteoroids and planetary surfaces is dominated by reactions of secondary neutrons [1]. But, experimental cross sections for n-induced reactions above 14 MeV are generally sparse and for all relevant cosmogenic nuclides practically not existent [2]. Therefore, frequently the assumption of equal cross sections of p- and n-induced reactions is made in model calculations of production rates. However, this assumption is generally not valid and may lead to false production rates. Assuming, for example, equal proton and neutron cross sections for the reactions $O(p,5pxn)^{10}Be$ and $O(n,4pxn)^{10}Be$, the production of ^{10}Be from oxygen in an artificial stony meteoroid irradiated with 1.6 GeV protons is underestimated by up to a factor of two (Fig. 1). Since O is the most important target element for the production of ^{10}Be in stony meteoroids and since the terrestrial simulation closely matches the irradiation conditions in space, an analogous underestimate would result in model calculations of real meteoroids.
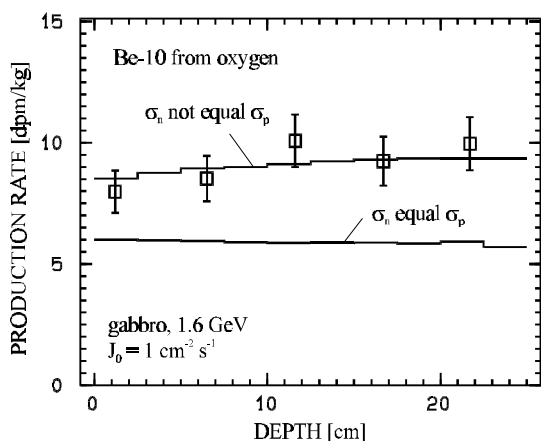
Fig. 1. Experimental and calculated production rates of ^{10}Be from O in an artificial stony meteoroid made of gabbro [3]. Both theoretical production depth profiles are based on experimental cross sections [4] for the p-induced production, one assumes equal neutron and proton cross sections and one uses the neutron cross sections described here.

The required cross sections of neutron-induced reactions can be derived from experimental thick-target production rates [5] or from thin-target irradiations using accelerator-based medium-energy neutron sources [6]. In both cases excitation functions can only be determined by unfolding techniques from the measured production rates starting from theoretical guess functions. Here, we present a consistent set of neutron excitation functions for more than 500 target/product combinations [7,8] derived from production rates measured in artificial stony and iron meteoroids irradiated isotropically with 600 MeV and 1.6 GeV protons [3,5,9–11]. These neutron cross sections provide a basis for physical model calculations describing all aspects of cosmogenic nuclide production in extraterrestrial matter, [e.g., 12,13]. In addition, we report on new experiments at Louvain la Neuve and Uppsala with neutron beams produced via $^7Li(p,n)^7Be$ covering n-energies from 30 MeV to 180 MeV.

References: [1] Michel R. et al. (1991) *Meteoritics, 26,* 221–242. [2] Michel R. (1991) in: Kocherov N.P. (ed.), *Intermediate Energy Nuclear Data for Applications*, INDC(NDS)-245, 17 (IAEA, Wien, 1991) 17–36. [3] Michel R. et al. (1995) *Planet. and Space Sci, 43,* 557–572. [4] Schiekel Th. et al.(1996) *Nucl. Instr. Meth. Phys. Res., B114,* 91–119. [5] Michel R. et al. (1997) in: Condé H. (ed.) *Proc. 2nd Int. Conf. on Accelerator-Driven Technologies and Applications, 3.–7. Juni 1996, Kalmar, Schweden*, Uppsala University, Gotab, Stockholm, 448–454. [6] Neumann S. et al. (1997) in: Reffo G. et al. (eds.), *Conf. Proc. Vol. 59 "Nuclear Data for Science and Technology,"* Società Italana di Fisica, Bologna, 379–383. [7] Leya I. (1997) thesis, University of Hannover. [8] Leya I. and Michel R. (1997) in: Reffo G. et al. (eds.), *Conf. Proc. Vol. 59 "Nuclear Data for Science and Technology,"* Società Italana di Fisica, Bologna, 1463–1467. [9] Michel R. et al. (1986) *Nucl. Instr. Meth. Phys. Res., B16,* 61–82. [10] Michel R. *et al.* (1989) *Nucl. Instr. Meth., B42,* 76–100. [11] Michel R. (1994) in: Dickens J. K. (ed.) *Proc. Int. Conf. Nuclear Data for Science and Technology*, Am. Nucl. Soc., Inc., La Grange Park, Illinois, 377–379. [12] Michel R. et al. (1996) *Nucl. Instr. Meth. Phys. Res., B113,* 434–444. [13] Leya I. and Michel R. (1997) *Meteoritics & Planet. Sci., 32,* A78–A79.

THE EXPOSURE AGE DISTRIBUTION OF ENSTATITE CHONDRITES. A. Patzer and L. Schultz, Max-Planck-Institute for Chemistry, D-55020 Mainz, Germany.

In 1981 Crabb and Anders [1] reported noble gases in enstatite chondrites and calculated the exposure ages of 18 specimens. Since then many new enstatites have been recovered, especially from Antarctica and hot deserts. We present here new noble gas measurements of 38 individual E-chondrites, 24 specimens are investigated for noble gases the first time.

Bulk concentration and isotopic composition of He, Ne and Ar (sample weights between 80 and 100 mg) were analysed using an apparatus and procedure described recently [2]. Each noble gas consists of different components of distinct origin. The cosmogenic part was determined on the supposition of a certain isotopic composition of trapped components. Exposure ages were calculated with production rates derived from the mean chemistry of E-chondrite groups according to [3–5].

Hellium-3, Neon-21, and Argon-38 cosmic ray exposure ages are not concordant in many cases. Lower [3]He ages - as also observed in many ordinary chondrites - are explained by diffusive loss due to solar heating on orbits with small perihelion distances. Some E-chondrites, however, show also low [38]Ar-exposure ages compared to the [21]Ne age. This might be the result of terrestrial weathering with loss of cosmogenic [38]Ar from metal. We consider the [21]Ne-exposure ages to be the most reliable and use them for the discussion. The cosmogenic $^{22}Ne/^{21}Ne$ in E-chondrites is less effective as shielding parameter because of lower Mg contents [6]. So, the [21]Ne-ages may have larger uncertainties (about 20%) than those estimated for ordinary chondrites.

Fig. 1 represents the histogram of [21]Ne-exposure ages of E-chondrites. Ages range from about 1 to 65 Ma. Three diffuse clusters seem to evolve at about 2–5, 9 and 40 Ma, however, statistics is still insufficient to support firm conclusions. No difference between individual E-chondrite types is observed.

Pairing of meteorite specimens found in Antarctica may be recognized by similar noble gas records. Taking also into account find localities and classifications, the Allan Hills meteorites 84170 and 84206 as well as 88046 and 88070, respectively, are paired. Two meteorites from the Yamato Mountains seem to originate from the same meteoroid (Y791790 and Y791810), too.

About 10% of all E-chondrites are regolith breccias as demonstrated by abundant solar noble gases. Four samples reported here (ALH 84170/84206, ALH 88046/88070, ALH 85119, MAC 88136) belong to this category.

References: [1] Crabb J. and Anders E. (1981) *GCA, 45,* 2443–2464. [2] Scherer P. et al. (1998) *Meteoritics and Planet. Sci., 33,* 259–265. [3] Kong P. et al. (1997) *GCA, 61,* 4895–4914. [4] Mason B. (1979) *Data of Geochemistry 6th Ed.,* B 1. [5] SchultzL. and Freundel M. (1984) *Isotopic ratios in the Solar System*, 23–33. [6] Eugster O. (1988) *GCA, 52,* 1649–1662.

Fig. 1. Neon-21 cosmic ray exposure ages of Enstatite chondrites.
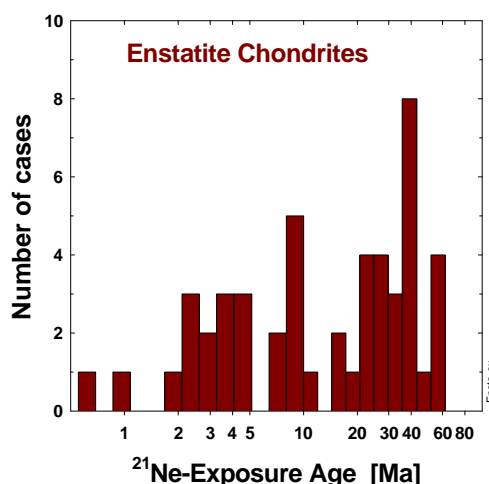
COSMIC-RAY EXPOSURE AGES OF THE TWO IRON METEORITES, RAFRÜTI AND NINGBO, AND THE TWO MESOSIDERITES, WEIYUAN AND DON UJIMQIN.

D. Terribilini[1], O. Eugster[1], S. Vogt[2], and D. Wang[3], [1]Physikalisches Institut, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland (terri@phim.unibe.ch), [2]Department of Chemistry, Purdue University, West Lafayette IN 47907-1396, USA, [3]Institute of Geochemistry, Academia Sinica, Wushan, Guangzhou 510640, People's Republic of China.

Introduction: In this work we analyzed the noble gas inventory, the radionuclides [10]Be, [26]Al and [36]Cl, and (for some of the samples) the mineralogical composition of two iron meteorites and two mesosiderites. Rafrüti (anomalous ataxite, found 1886) is the oldest swiss meteorite for which there exist no noble gas measurements until now. Our analysis shows a relatively high He loss (66% [3]He and 25% [4]He), probably due to heating by the farmer who found it. Rafrüti is not chemically related to any other meteorite class and has the lowest Ir content of all iron meteorites. Ningbo (octaedrite, fall 4.10.1975), a Chinese meteorite, belongs to the IVA group; the noble gas content has been analyzed by [7] before. In addition we studied two Chinese mesosiderites: Don Ujimqin (fall 7.09.1995), a type I mesosiderite and Weiyuan (found 1978), a type III mesosiderite.

Results: The major component consists of the cosmogenic noble gases (Table). For Rafrüti and Ningbo we observe [3]He and [4]He loss and corrections were applied using the diagrams of Jeannot [3]. Based on a single-stage exposure model we derived the production rates using five different methods (Table 1).

Exposure Ages: Rafrüti has an extremely short average exposure age of 9.2±0.2 Ma (Table). Typical exposure ages for the iron meteorites are between 100 and 1000 Ma. For Ningbo we observe an average exposure age of 202±13 Ma. A compilation for iron meteorites of type IVA [5] shows that this meteorite has a relatively short exposure age.

Our analysis for the two mesosiderites yield average exposure ages of 161 Ma for Don Ujimqin and 15.6 Ma for Weiyuan. These values are consistent with the exposure ages of 14 mesosiderites analyzed by Begemann [1].

References: [1] Begemann F. et al. (1976) *GCA, 40,* 353–368. [2] Eugster O. (1988) *GCA, 52,* 1649–1662. [3] Jeannot J.-P. (1997) Thèse de doctorat. [4] Signer P. et al. (1985) *Meteoritics, 20,* 757–759. [5] Voshage H. and Feldmann H. (1979) *EPSL, 45,* 293–308. [6] Voshage H. (1984) *EPSL, 71,* 181–194. [7] Weber H. W. et al. (1986) *Geochemistry, 5,* 320–330.

TABLE 1. Concentration of the cosmogenic noble gases and cosmic-ray exposure ages of Rafrüti, Ningbo, Weiyuan, and Don Ujimqin.

	[3]He	[4]He	[21]Ne	[38]Ar		T3	T4	T21	T38
	10^{-8}ccSTP/g					Ma			
Rafrüti	6.53	26.05	0.081	0.420		—	9.23	9.00	9.35[*]
						—	9.08	8.96	—[†]
						—	—	9.33	—[‡]
Ningbo	165	624	2.030	10.01		—	210	204	209[*]
						—	199	191	—[†]
Don Ujimqin									
Si	194	1011	40.10	23.14		114	—	118	207[§]
FeNi	189	693	8.930	14.97		—	—	—	174[¶]
Weiyuan									
Si	26.76	139	5.783	2.335		15.8	—	19.0	20.3[§]
FeNi	11.47	42.17	1.974	1.098		—	—	—	12.8[¶]

[*]Production rates from [3] (equations 43-44).

[†]Production rates from [6].

[‡]P21 of [4].

[§]Production rates from [2].

[¶]Mean production rate from 14 mesosiderites [1].

IRON-60 IN METEORITES. S. Merchel[1*], U. Herpers[1], K. Knie[2], T. Faestermann[3], G. Korschinek[3], M. Gloris[4], and R. Michel[4], [1]Abteilung Nuklearchemie, Universität zu Köln, 50674 Köln, Germany, (silke.merchel@uni-koeln.de), [2]Max-Planck-Institut für Astrophysik, 85740 Garching, Germany, [3]Fakultät für Physik, Technische Universität München, 85748 Garching, Germany, [4]Zentrum für Strahlenschutz und Radioökologie, Universität Hannover, 30167 Hannover, Germany, [*]present adress: Max-Planck-Institut für Chemie, 55020 Mainz, Germany.

Measurements of cosmogenic nuclides in meteorites are necessary to test and improve the physical models with which we try to understand the course of events in space. Furthermore, radionuclides archive information about the cosmic radiation and the meteorites themselves e.g. their exposure history.

One of the most interesting cosmogenic nuclide is ^{60}Fe. The only relevant targets for the production of ^{60}Fe in extraterrestrial matter are the two heavy nickel isotopes. Because of their rare abundances of 3.6 % (^{62}Ni) and 0.9 % (^{64}Ni) of natural nickel and the low cross sections of nuclear reactions, the production rate is expected to be very low. Furthermore, there are two difficulties to measure this long-lived radionuclide ($T_{1/2}$ = 1.49 My [1]). On the one hand, counting is only possible via detection of the daughter nuclide ^{60}Co after radiochemical separation and waiting for ^{60}Co built-up. This method was first and only done by Goel and Honda [2] with about 2.5 kg of the iron meteorite Odessa. On the other hand, the generally high content of natural iron in extraterrestrial matter results in low ^{60}Fe/Fe ratios of about 10^{-14} which need special features to make it measurable via accelerator mass spectrometry (AMS). Besides of one attempt at the Argonne National Laboratory in the iron meteorite Treysa [3], we present the first ^{60}Fe AMS data of meteorites.

After improving the gas-filled analyzing system GAMS [4] and radiochemical separation methods, we were able to measure meteorite samples at run times of about 1 hour. In detail, we measured the ^{60}Fe activities in two iron meteorites (Dermbach, Tlacotepec) and in magnetic fractions of the mesosiderite Emery and the LL chondrite Saint-Séverin. They show, as expected, a strong correlation to the nickel content of the samples.

Furthermore, we calculated theoretical depth- and size-dependent production rates of ^{60}Fe by galactic cosmic ray (GCR) particles in analogy to earlier model calculations [5] based, however, on purely theoretical cross sections for the n- and p-induced production. In spite of this crude approximation, the theoretical production rates for iron meteoroids, normalized to the main target element nickel, are in good agreement with the experimental values of Dermbach and Tlacotepec (Fig. 1).
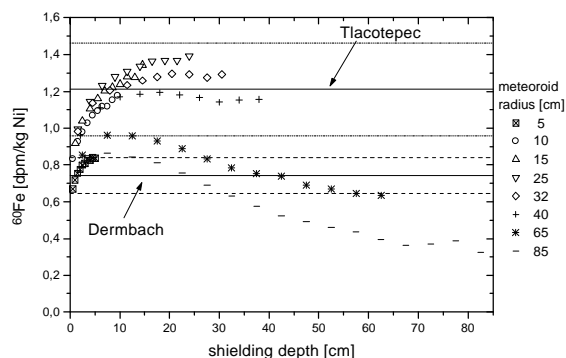
Fig. 1. Theoretical depth- and size-dependent production rates of ^{60}Fe in iron meteoroids by GCR particles on the basis of physical model calculations in comparison to experimental data of the iron meteorites Dermbach and Tlacotepec.

Due to the large errors of the determination of ^{60}Fe we cannot estimate a preatmospheric radius of the meteoroid or a shielding position of the analyzed sample from this radionuclide alone. But, together with measurements and calculations of other cosmogenic nuclides e.g. ^{10}Be, ^{26}Al, ^{53}Mn, we can reveal the exposure and terrestrial history of meteorites. Last but not least, there is a big advantage of ^{60}Fe: Its production rates are - in contrast to those of almost all cosmogenic nuclides - nearly independent of the chemical composition of the meteorite. Direct comparison by normalizing to nickel contents is possible through all types of iron and stony meteorites.

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